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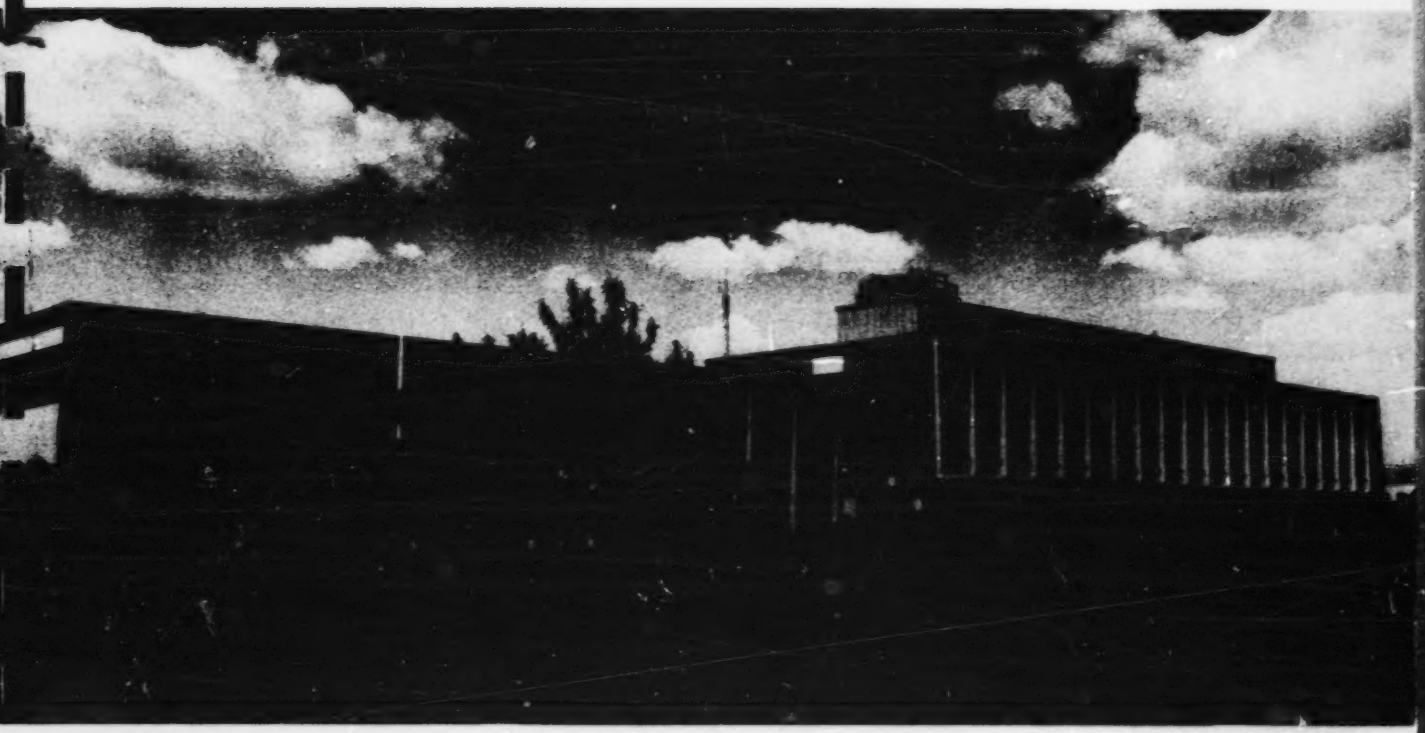

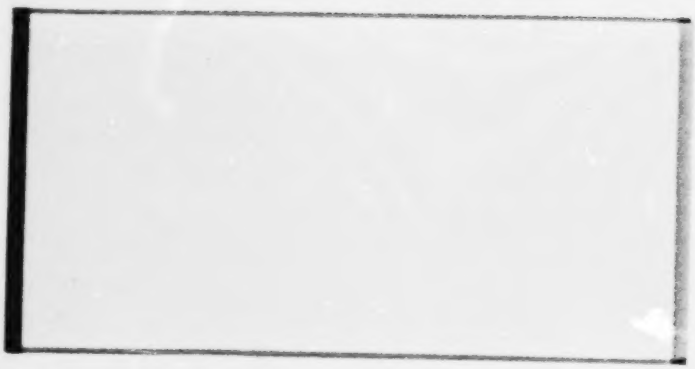

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INVESTIGATION INTO THE USE OF CLADOCERAN ASSEMBLAGES TO INFER LAKE pH

Report No 82-398-K

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ABSTRACT

Cladoceran remains in the surficial sediment of 24 shield lakes of varying pH and heavy metal levels were investigated to assess the usefulness of this group in inferring lake pH. The objective was to develop a cladoceran-pH inference system that could be used to document the pH history of an acid lake by analysis of cladoceran remains in a lake sediment core. Reduced number of species in lower pH lakes found by several investigators was not found for the cladoceran remains in the surficial sediments of the lakes studied here nor was the distribution of their remains in relation to pH consistent with that described in the literature. No correlations were found between the relative abundances of individual taxa and individual chemical and physical parameters of the lakes. Phosphorous, an indicator of the trophic status of the lake, was identified as a main discriminant variable determining species composition and may have masked any effect of pH. The Cladocera were not found to be useful in inferring lake pH since no relationship was identified between their species composition in the surficial sediments and the pH of the 24 study lakes.

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To Mr. F.J. Kee
Director of Research

INVESTIGATION INTO THE USE OF CLADOCERAN ASSEMBLAGES TO INFER LAKE pH

INTRODUCTION

Sulfur and nitrogen oxides emitted by the burning of fossil fuels have been implicated as the causal factor to increasing acidity of rain and snow. In South-central Ontario the mean pH of precipitation between May, 1976, and April, 1977, ranged between 4.0 and 4.4 with frequent event pH below 4.0 (Dillon et al 1978).

It is believed that at present and in the near past a large number of lakes have undergone acidification. Acid lakes have been indentified in the Sudbury area and in the La Cloche Mountain lakes. However, there is an apparent lack of historical pH documentation for these acidic lakes. Therefore the Research Division has initiated a program to document the history of an acidified lake through the analysis of cladoceran remains in lake sediment cores. As a first step, their usefulness in inferring lake pH was investigated.

A literature review investigating the possibility of using zooplankton remains in sediments to document pH history of acid lakes has been prepared (OHRD Report No 80-295-K). Studies on the distribution of zooplankton in relation to pH have indicated that lakes of low pH (<5) are poor in species composition. This suggests that some taxa disappear during the process of acidification, although it is not known whether this is due to direct physiological effects of acids or increased levels of heavy metals, a change in the available food supply, or changes in the predator-prey relationships. On the basis of a reduction in zooplankton taxa it was considered feasible to develop a zooplankton-pH inference system.

To investigate the relationship between current lake pH and recently sedimented cladoceran remains, surficial sediment samples were collected from 24 shield lakes of varying pH and levels of heavy metals. The lakes were located within a 200 km

radius of Sudbury (Figure 1) and all had a surface area of less than 200 ha with maximum depth generally greater than 20 m. Since remains of Cladocera preserve well in the sediment and are sufficiently abundant for statistical consideration they were chosen for the analysis. The objective of this study was to develop a pH inference system based on the cladoceran assemblages identified in the surficial sediment samples of the 24 lakes. If an inference system is developed it could be used to document the pH history of an acid lake by analysis of cladoceran assemblages in a sediment core.

METHODS

Biological Data

Surficial sediment samples were collected from the 24 lakes shown in Figure 1 between mid-September and early October. The collection method is described in OHRD Report No 82-273-K. Since cladoceran remains in the sediments are highly fragmented (i.e. head shields, post-abdominal claws, carapaces) and are difficult to identify, live limnetic zooplankton samples were collected at the deepest point of each lake and littoral zooplankton samples were taken in lakes accessible by road (OHRD Report No CB81-6-H) to aid in the identification of cladoceran fragments in the sediment samples. The sedimentary remains were analysed as described in Ontario Hydro Research Division Report No. CB81-12-K. For each lake a minimum of 250 recognizable cladoceran remains were counted and identified to species level when possible. The most frequently occurring anatomical part was taken as representing that species and each occurrence was taken to represent an individual. The data for each taxa was expressed as a percentage of the total number.

CHEMICAL AND PHYSICAL DATA

Two sources of chemical and physical characteristics of the lakes were used. One set is 1980 data (1 and 7m) collected in conjunction with the surficial sediment samples. A full description of the analytical methods and results are presented in Ontario Hydro Research Division Report No 82-273-K. A second set of data was obtained from the Sudbury Environmental Study conducted in 1974-1976 (MOE 1978). The data are presented in Tables 1 and 2. Since sedimentary remains were probably accumulated over several years both sets of chemistry data were used. The Sudbury Environmental Study data set also provided nutrient data which had not been measured in 1980.

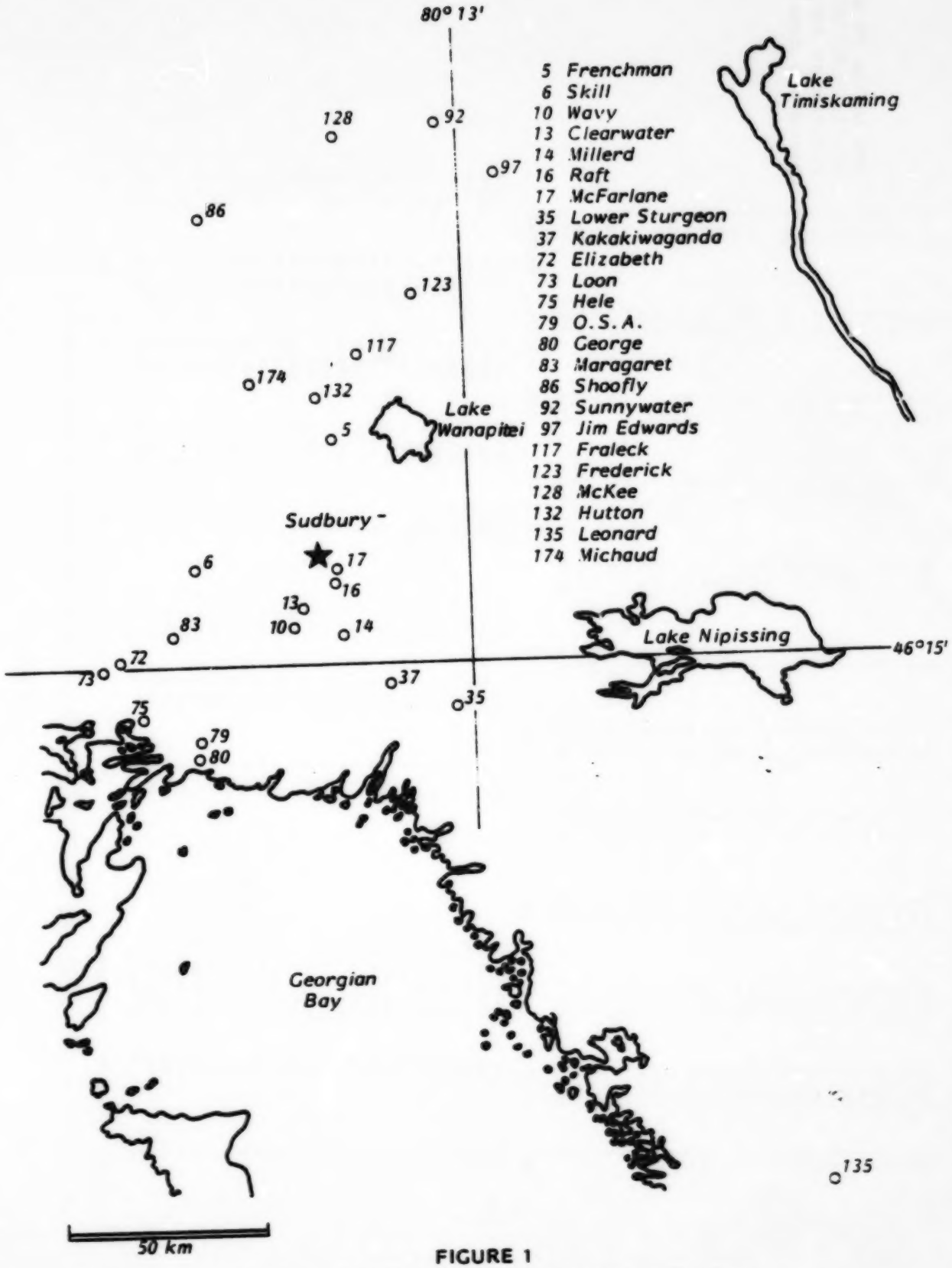

FIGURE 1

LOCATION OF LAKES SAMPLED IN SEPTEMBER, 1980. LAKES NUMBERED ACCORDING TO OME (1978).

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TABLE 1

CHEMICAL AND PHYSICAL PARAMETERS* OF LAKES - 1980 DATA

OBS	LAKENUM	LAKENAME	AL	BA	CA	CR	FE	K	MG	MN
1	5	FRENCHMAN 5	35.0	16.0	4045.0	1.4	145.0	300.0	917.0	47.0
2	6	SKILL 6	40.0	9.0	7510.0	2.2	470.0	650.0	1360.0	261.0
3	10	HAVY 10	310.0	40.0	3160.0	17.0	275.0	400.0	904.0	195.0
4	13	CLEARWATER 13	345.0	59.0	5840.0	4.2	255.0	600.0	1395.0	265.0
5	14	MILLERD 14	65.0	70.0	5250.0	2.9	65.0	600.0	2150.0	5.0
6	16	RAFT 16	30.0	19.0	5065.0	2.5	70.0	650.0	1620.0	192.0
7	17	MCFARLANE 17	30.0	19.0	15050	4.7	65.0	1600.0	4865.0	3.0
8	35	LOWER STURGEON 35	65.0	10.0	3860.0	2.8	110.0	600.0	1650.0	7.0
9	37	KAKAKIWAGANDA 37	30.0	11.0	5470.0	3.1	105.0	650.0	2455.0	82.0
10	72	ELIZABETH 72	35.0	5.0	9025.0	2.5	55.0	500.0	1740.0	5.0
11	73	LOON 73	45.0	9.0	6035.0	3.1	130.0	600.0	1705.0	33.0
12	75	HELE 75	45.0	22.0	3715.0	1.6	65.0	350.0	1235.0	6.0
13	79	O.S.A. 79	290.0	37.0	3040.0	1.1	125.0	300.0	787.0	269.0
14	80	GEORGE 80	165.0	61.0	3125.0	3.3	150.0	400.0	917.0	128.0
15	83	MARGARET 83	30.0	8.0	5037.0	1.7	55.0	300.0	1075.0	5.0
16	86	SHOOFLY 86	70.0	33.0	34700	4.4	95.0	600.0	4385.0	5.0
17	92	SUNNYWATER 92	245.0	180.0	1795.0	2.1	150.0	200.0	420.0	205.0
18	97	JIM EDWARDS 97	255.0	184.0	2355.0	2.7	65.0	400.0	661.0	198.0
19	117	FRALECK 117	60.0	51.0	3525.0	1.6	35.0	400.0	894.0	57.0
20	123	FREDERICK 123	300.0	71.0	4665.0	1.6	100.0	400.0	868.0	237.0
21	128	MCKEE 128	85.0	42.0	12050	4.9	100.0	300.0	2700.0	4.0
22	132	HUTTON 132	95.0	41.0	4905.0	1.6	85.0	500.0	1200.0	7.0
23	135	LEONARD 135	50.0	31.0	2820.0	1.5	815.0	350.0	631.0	69.0
24	174	MICHAUD 174	175.0	50.0	3005.0	2.3	155.0	350.0	834.0	73.0

OBS	NA	SI	SR	TI	ZN	CU	NI	PH	ALK	O2	MAXDEPTH
1	900.0	10.0	20.1	1.0	38.0	5.1	25.0	6.1	65.0	0.0	18.0
2	1100.0	10.0	17.7	1.0	3.0	3.3	8.0	6.7	73.0	0.0	16.0
3	1100.0	77.0	19.5	3.0	38.0	19.6	68.0	4.9	0.0	2.6	21.5
4	2000.0	260.0	26.5	1.0	52.0	57.0	224.0	4.5	0.0	2.7	18.0
5	1550.0	175.0	25.1	1.0	75.0	10.1	24.0	7.6	245.0	2.0	19.0
6	1250.0	10.0	22.4	1.0	11.0	8.2	72.0	7.2	25.0	3.6	13.5
7	23050	70.0	42.5	1.0	8.0	8.1	78.0	7.4	202.0	1.9	15.5
8	1100.0	10.0	17.0	2.0	12.0	2.8	6.0	6.4	53.0	7.6	41.0
9	4400.0	45.0	22.5	1.0	6.0	3.2	9.0	7.0	83.0	4.4	23.0
10	1350.0	10.0	17.1	1.0	7.0	1.8	6.0	7.4	152.0	0.0	23.5
11	1650.0	10.0	16.5	1.0	38.0	2.5	5.0	7.1	99.0	0.9	20.5
12	900.0	385.0	17.0	1.0	15.0	2.1	1.0	6.6	19.0	0.4	42.3
13	750.0	10.0	15.7	1.0	43.0	4.1	10.0	4.7	0.0	4.3	40.0
14	900.0	80.0	19.3	1.0	46.0	2.3	8.0	5.5	0.0	3.4	40.0
15	500.0	10.0	12.6	1.0	101.0	2.8	4.0	7.0	47.0	0.5	14.3
16	1250.0	1515.0	12.8	1.0	101.0	1.3	3.0	8.2	786.0	0.6	29.0
17	650.0	295.0	11.9	3.0	29.0	0.9	2.0	4.9	0.0	4.4	37.0
18	950.0	715.0	16.6	3.0	33.0	0.8	4.0	5.3	0.0	3.6	19.5
19	900.0	820.0	16.2	1.0	86.0	1.9	5.0	5.9	10.0	2.3	13.0
20	800.0	30.0	17.4	1.0	86.0	3.4	12.0	4.3	0.0	3.3	16.0
21	1300.0	125.0	15.7	3.0	40.0	1.2	3.0	7.5	256.0	2.5	23.0
22	950.0	265.0	19.6	1.0	35.0	2.7	2.0	5.9	26.0	0.0	15.0
23	1700.0	410.0	14.9	2.0	22.0	0.8	1.0	6.0	2.0	0.0	13.5
24	850.0	10.0	15.5	1.0	76.0	2.2	7.0	5.6	5.0	0.1	23.0

*Elemental concentration in µg/L, alkalinity, O_2, and depth in m.

TABLE 2

CHEMICAL AND PHYSICAL CHARACTERISTICS OF LAKES, 1974-1976 MOE DATA

OBS	LAKE NUM	LAKE NAME	km DIST SUD	ha SURFACE AREA	$10^6 m^3$ VOLUME	m MEAN DEP	µmhos/cm CONDUCT	mg/L SO3	mg/L SIO2	µg/L KJELDAHL	µg/L FREEN H4	µg/L NO2	µg/L NO3	µg/L TOTP	µg/L SOLP	m SECCHI	mg/m³ CHLORPHL
1	5	FRENCHMAN 5	29	41.7	2.2	5.3	48.0	16.8	1.0	162.0	19.0	1.0	11.0	5.0	1.0	4.8	2.8
2	6	SKILL 6	27	103.2	5.3	5.1	46.0	12.1	0.7	337.0	50.0	2.0	11.0	13.0	3.0	2.5	3.0
3	10	NAVY 10	21	255.1	.	.	60.0	16.1	3.0	164.0	37.0	1.0	109.0	5.0	1.0	8.5	0.4
4	13	CLEARWATER 13	24	76.9	6.3	8.2	89.0	24.5	3.6	85.0	15.0	1.0	51.0	4.0	1.0	7.5	0.6
5	14	MILLERD 14	24	176.6	8.2	4.6	67.0	20.0	1.2	283.0	31.0	2.0	23.0	12.0	4.0	4.1	3.3
6	16	RAFT 16	10	95.5	.	.	70.0	24.9	1.0	167.0	13.0	1.0	15.0	5.0	1.0	5.9	2.1
7	17	MCFARLANE 17	10	140.5	10.2	7.3	193.0	28.0	1.0	270.0	50.0	1.0	19.0	12.0	3.0	3.3	3.4
8	35	LOWER STURGEON 35	48	82.2	.	.	52.0	12.3	1.5	345.0	44.0	3.0	25.0	12.0	5.0	3.3	2.9
9	37	KAKAKIWAGAMDA 37	40	187.8	18.2	9.7	82.0	15.0	1.8	317.0	27.0	3.0	39.0	9.0	1.0	3.1	4.1
10	72	ELIZABETH 72	48	122.2	14.3	11.7	71.0	12.2	1.0	240.0	12.0	2.0	29.0	6.0	2.0	4.4	2.9
11	73	LOON 73	56	151.0	11.5	7.6	61.0	11.9	1.5	307.0	12.0	3.0	37.0	9.0	1.0	3.9	1.7
12	75	NELE 75	56	68.3	14.8	21.7	41.0	10.9	1.5	154.0	9.0	2.0	17.0	3.0	1.0	5.1	1.0
13	79	O.S.A. 79	56	291.5	34.5	11.8	47.0	13.0	0.5	88.0	21.0	2.0	217.0	2.0	1.0	15.7	1.0
14	80	GEORGE 80	56	147.9	27.5	18.6	40.0	12.5	1.9	122.0	19.0	1.0	122.0	5.0	1.0	12.0	0.6
15	83	MARGARET 83	40	55.5	.	.	46.0	12.1	1.2	254.0	20.0	2.0	9.0	7.0	2.0	3.3	2.2
16	86	SHOOFLY 86	97	185.3	12.6	6.9	188.0	9.3	3.6	210.0	10.0	1.0	9.0	7.0	1.0	8.7	1.1
17	92	SUNNYWATER 92	101	141.7	34.1	24.1	41.0	10.7	0.9	132.0	31.0	1.0	92.0	4.0	2.0	17.2	0.7
18	97	JIM EDWARDS 97	105	82.6	7.5	9.1	40.0	11.6	1.9	126.0	15.0	1.0	9.0	3.0	1.0	8.4	0.8
19	117	FRALECK 117	48	173.9	11.9	5.8	47.0	13.6	2.7	202.0	21.0	2.0	28.0	10.0	1.0	5.8	2.6
20	123	FREDERICK 123	85	174.1	.	.	57.0	16.6	0.6	106.0	14.0	1.0	44.0	4.0	1.0	11.2	1.2
21	128	MCKEE 128	101	164.0	24.4	14.9	81.0	9.8	2.3	240.0	18.0	2.0	18.0	9.0	2.0	3.7	2.1
22	132	HUTTON 132	37	66.4	.	.	44.0	11.1	0.5	208.0	16.0	1.0	9.0	6.0	1.0	4.4	2.2
23	135	LEONARD 135	198	187.0	14.3	7.7	34.0	8.0	0.3	196.0	13.0	1.0	12.0	6.0	2.0	6.9	2.0
24	174	MICHAUD 174	42	132.0	.	.	38.0	12.2	1.0	154.0	20.0	1.0	13.0	5.0	1.0	6.7	1.0

DESCRIPTION OF DATA ANALYSIS

Univariate Analysis

As an initial attempt to identify relationships between the distribution of individual taxa and chemical and physical parameters, correlations were calculated.

Multivariate Analysis

The data were analyzed by multivariate methods in an attempt to identify patterns in the species composition of the lakes and to relate these patterns to physical and water chemical variables. Several techniques, based on different mathematical assumptions were attempted to ensure that the end results were not an artifact of the procedures used in their derivation. The classification techniques, mutual information analysis (OHRD Report No. 75-446-K) and cluster analysis (Mardia et at 1979) were used to group lakes with similar species composition. Mutual information analysis (MIA) produces a hierarchical ordering that groups samples containing similar relative abundances of species. T-tests were used to compare the relative abundances of dominant taxa of successive lake groups to test their uniqueness. Cluster analysis groups lakes according to Euclidian distance. Euclidian distance may show a low degree of resemblance between two quadrats in which all taxa are identical if the taxa values are greatly different, and conversely, a high degree of similarity when there are no taxa in common, if the species values are generally low (Orloci 1973). The ordination techniques, principal component analysis (Mardia et al 1979) and reciprocal averaging (Hill 1973) arranged the lakes spatially with relatively few dimensions and their proximity reflects similarity (Kirby 1976). Reciprocal averaging (RA) is an iterative procedure in which the final species scores are averages of the lake scores and reciprocally the lake scores are averages of species scores. In contrast to Principal Component Analysis (PCA) the analysis does not assume linearity, but has been observed to produce similar results when data analysed by PCA has been initially standardized to unit variance (Hill 1973). The RA gives greater weight to rare species than the PCA procedure used on the basis of covariance matrices. The similarity index used in the PCA described in this report was the covariance matrix. Discriminant analysis was used to determine whether lakes with differences in species composition were also different in terms of chemical and physical characteristics (Mardia et al 1979).

RESULTS AND DISCUSSION

The species composition of the Cladocera in the surficial sediment samples are presented in Table 3. The lakes are presented in order of increasing pH. No obvious trends with pH were apparent upon examination of the data. The reduced number of

zooplankton species in lower pH lakes found by several investigators (Sprules 1974, Hendrey et al 1975, and Roff and Kwiatkowski 1977) was not found in this study (Figure 2). In fact a larger number of the low pH lakes (pH<6) contained higher numbers of taxa than the medium (pH 6-7) and high pH (pH>7) lakes. *Eubosmina* spp was the only taxon which was common in lakes with pH<6 and absent from lakes with pH>6. However difficulty with the taxonomy of this taxon limits its usefulness as an indicator.

Of the 24 lakes included in our study, Clearwater lake had the lowest pH and highest levels of Al (345 ug/L), Cu (57 ug/L) and Ni (224 ug/L). A total of 8 taxa were found in the surficial sediment sample from this lake. A large number of lakes with pH>6 and lower levels of Al, Cu and Ni also contained 8 taxa or less. *Daphnia galeata mendotae* found in our sample was not found by Yan and Strus (1980) who studied Clearwater Lake extensively between 1973 and 1978. The mean pH (ice free period) of the lake during their study ranged from 4.1 to 4.4.

Brakke (1981) conducted a similar study to ours as part of the SNSF project in Norway. In his study the examination of sedimentary remains was limited to those of the Chydoridae of 17 lakes. He found that *Alona costata* and *A. quadrangularis* were uncommon or absent from lakes below pH 5.2. In our study *A. costata* was only found in Sunnywater Lake. The pH of this lake was 4.9. *A. quadrangularis* occurred in 9 of our lakes with pH ranging from 4.5 to 8.2.

Whiteside (1970) described *Alonella nana* as a species normally associated with low alkalinities in Denmark. In our study it was found in most of the low alkaline lakes as well as in several of the more alkaline lakes. Its relative abundance was highest (21%) in Shoofly Lake, the lake with the highest alkalinity.

Sprules examined the zooplankton in 47 acidic lakes of the La Cloche mountains and found *Leptodora kindtii* and *Daphnia galeata mendotae* to be absent from lakes with pH less than 5. In our study both species occurred in several lakes with pH below 5. However, Sprules (1975) only studied the midsummer crustacean zooplankton communities. With more frequent sampling Sprules may have found these two species in some of his low pH lakes. By sampling the surficial sediment our data included taxa present throughout the year and is therefore more complete. Roff and Kwiatkowski (1977) examined six lakes in the Sudbury area with pH ranging from 4.1 to 7.2. In these lakes *Leptodora kindtii* was only found in lakes with pH greater than 5 while *D. galeata mendotae* was found in all six lakes. Roff and Kwiatkowski's study only included six lakes compared to the 24 lakes included in our study and the trends they found in their lakes apparently do not apply to our larger set of lakes. Carter (1971) who examined the zooplankton of 32 ponds near the shore of Georgian Bay, Ontario, did not find *D. galeata mendotae* in ponds with pH less than 6.

TABLE 3

CLADOCERA SPECIES COMPOSITION (%) IN SURFICIAL SEDIMENT SAMPLES

Lakes	Clearwater	O.S.A.	Frederick	Bompastor	Wavy	Jim Edwards	George	Michael	Hutton	Fralick	Leonard	Franchere	Lower Sturgeon	Skill	Hale	Kakakamegosis	Margaret	Lore	Raft	McFarlane	Elizabeth	Nokes	Millard	Snoopy
pH	4.5	4.7	4.8	4.9	4.9	5.3	5.5	5.6	5.9	6.0	6.0	6.1	6.4	6.7	6.7	7.0	7.0	7.1	7.2	7.4	7.4	7.5	7.6	8.2
Taxa																								
Sididae			2.5	0.8	1.0						2.6	0.7	0.9			4.7	0.9		10.5	1.5			3.9	
Sida crystallina			4.9	1.6		1.2		0.6	2.8	1.3	1.3		0.9			1.6					0.7			
Diaphanosoma leuchtenbergianum					1.0						0.6					3.9		0.8	1.2		0.7		3.9	
Holopedidae																	1.8							
Holopedium gibberum							1.0				7.0													
Chydoridae																			1.2			0.8		1.9
Eurycercus bullatifrons			4.9		1.0	1.2				2.0	1.3			0.9			1.8							
Roncopilus diaper			0.8					1.2			0.6							0.8			0.7	1.7		19.1
Camptocercus sp				2.4		2.4	1.0	2.3	0.7	0.7	0.6	1.4						0.8				0.6		
Acroperus harpae								1.2		0.7	0.6						0.9							
Rhynchotalona falcata			0.8						0.7						0.9									
Graptoleberis testudinaria											1.3					0.8								
Leydigia sp			0.8	0.8		1.2		0.6	0.7													0.8	0.8	
Alona intermedia				0.8							0.6	0.7		0.9			0.9	0.8			0.7			5.7
Alona costata			0.8		1.0	1.2	1.0	1.2	0.7								0.9	2.3						1.0
Alona rostica		0.9							0.7			0.7					0.9							1.9
Alona guttata	4.0	0.9			1.0	4.7			2.1	0.7		0.7			0.8		0.9	0.8						3.8
Alona quadrangularis	1.0			0.8	1.0	1.2			0.7									0.8		0.7				21.0
Alona affinis				2.4									0.9				0.9	0.8				2.5		
Alona circumfimbriata				2.4		2.4	1.0	2.9	4.2	0.7	0.6													
Alona sp	2.0	0.9	1.6	8.7	2.0	5.9	1.0	2.3	9.0	0.7	1.3	0.7							0.8					1.0
Alonella nana		0.9	0.2					0.6	0.7	0.7							0.9							
Alonella excisa	1.0			0.8	1.0			1.2	0.7		0.6	1.4												2.9
Alonella azoica								0.6																
Alonella sp							1.0										1.8							
Disparalona rostrata					1.0	1.2		1.2		0.7														2.9
Disparalona dentivostris				0.8					2.1															
Disparalona sp					0.1																			
Pleuroxus denticulatus					0.1					1.3	0.6			0.9			0.9							2.9
Pleuroxus trigonellus		0.9	4.1			1.2		0.6	2.1								0.9							
Chydorus piger			0.8						0.7								5.4	3.1	1.2	1.5	11.1	0.8	0.9	2.9
Chydorus faviformis				0.8					0.7	1.3				0.9		15.5								
Chydorus gibbus	4.0	1.8	0.8		0.1			0.6	0.7	0.7							4.5	0.8	1.2		1.5			1.9
Chydorus sphaericus		0.9	1.6			1.2		0.6																
Chydorus bicornutus																								
Chydorus spp																								
Bosminidae	85.2	86.2	28.7	22.1	78.2	14.1	93.0	26.4	55.6	67.1	30.6	85.2	68.8	92.2	92.8	52.7	76.8	57.4	81.4	80.7	81.5	79.2	72.1	32.4
Bosmina longirostris											0.6													
Eubosmina tubicen		2.8	14.8	49.6		28.2		1.2		0.7	10.2					2.3				3.5				
Eubosmina spp						2.4				0.7	7.6													
Eubosmina tubicen/E. hagmani																								
							1.0				0.6					0.8							0.8	
Macrothricidae								0.6																
Ophryoxus gracilus	1.0																							
											1.0								0.8					
Daphnidae											17.8	7.0							17.8		9.6		7.5	12.4
Ceriodaphnia sp		0.9	4.9			1.2		0.6	1.4		5.1	1.4	15.6	1.7	6.3	4.7								
Daphnia pulex	1.0	1.8	9.0	1.6	2.0	10.6		27.6	1.4	12.1						2.3			7.8		5.2	2.2	5.0	3.9
Daphnia galeata mendotae											6.4		12.8	2.6		4.7								
Daphnia retrocurva			9.0	1.6	3.0	17.7		24.7	10.4	7.4									3.1					0.8
Daphnia sp								1.2	0.7		0.6													
Polyphemidae		0.9		0.8	2.0																			
Polyphemus pediculus																4.7			1.6		0.7		0.8	0.8
Leptodoridae				0.8	1.6	1.0		0.6	1.4	0.7														
Leptodora Kindtii																								

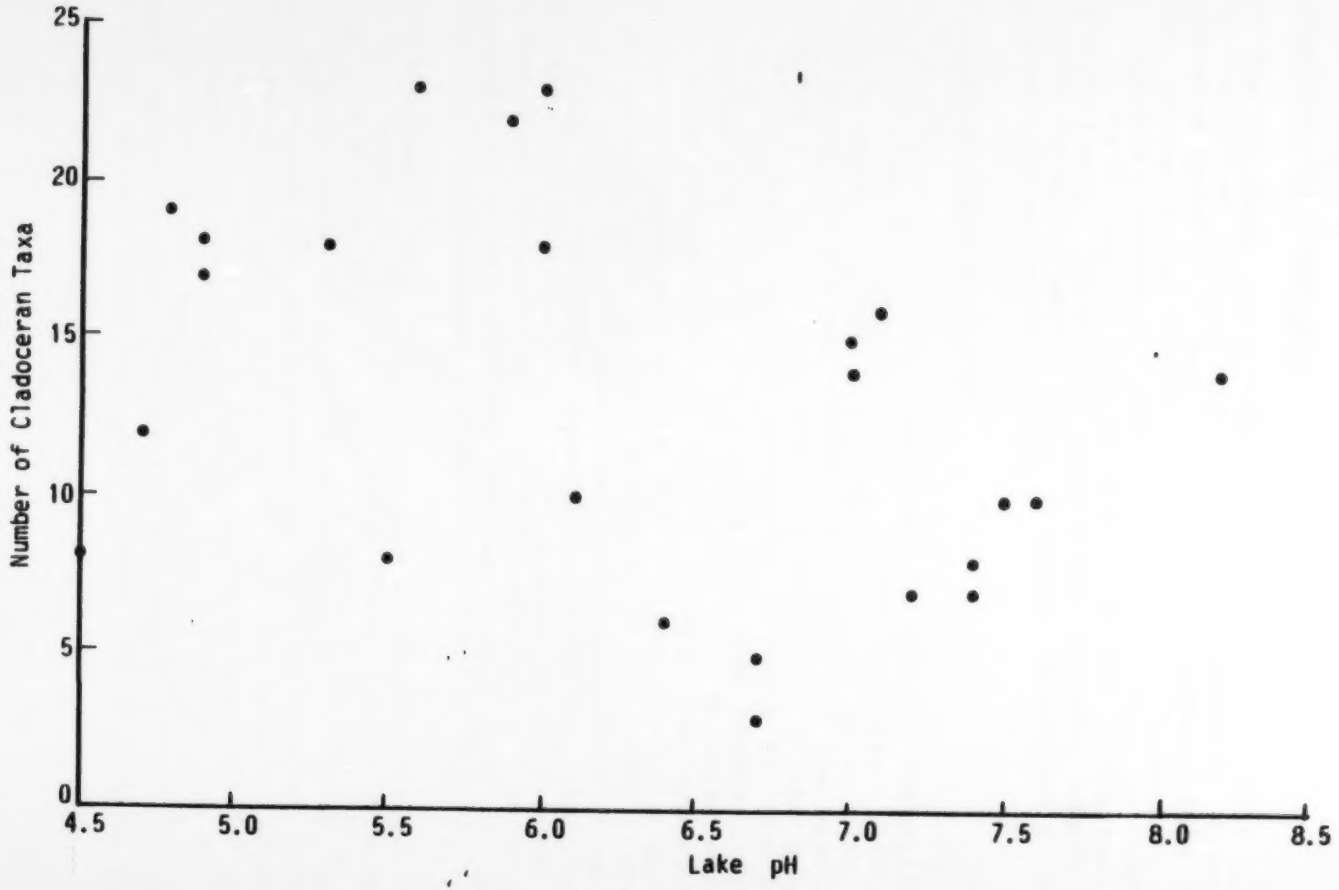

FIGURE 2
NUMBER OF CLADOCERAN TAXA VERSUS LAKE pH

It appears then that our data is not consistent with the distribution of taxa relative to pH indicated in the literature.

Univariate Data Analysis

When the relative abundances of individual taxa were correlated with individual chemical and physical parameters, no relationships were found with most r values considerably less than 0.50. Plots of the relative abundances of *Bosmina longirostris*, *Eubosmina* spp, *Chydorus sphaericus* and *Alonella nana* versus lake pH are presented in Figures 3,4,5 and 6 respectively. These taxa were among the more common taxa and occurred in sufficiently large relative abundances to allow for the detection of relationships.

Multivariate Data Analysis

The lakes were grouped on the basis of species composition using mutual information analysis and cluster analysis. Similar lake groupings were obtained using the two techniques. The lake groups formed by MIA and cluster analysis and the mean relative abundances (%) of the ten most abundant taxa in the samples included in the groups are presented in Table 4. The analysis separated out Lakes Michaud, Frederick, Jim Edwards, Sunnywater, Leonard and Shoofly from the remainder of the lakes which were placed into groups 1 and 3. The six lakes that separated out had lower relative abundances of *B. longirostris*, a species that was dominant (>50 %) in the remainder of the lakes. Michaud Lake contained large proportions of *D. galeata mendotae* and *Daphnia* spp (unidentified daphnids), Frederick, Jim Edwards and Sunnywater lakes contained a high proportion of *Eubosmina* spp (unidentified eubosminids), Leonard Lake had a high proportion of *Daphnia pulex* and Shoofly Lake had a high relative abundance of the chydorids, *Alonella nana* and *Acroperus harpae*.

PCA and RA were used to arrange the lakes spatially. With PCA taxa with high positive or negative coefficients were most highly correlated with a component while taxa with 0 or near 0 coefficients were not related to the pattern. In PC1 *Alonella nana*, *Eubosmina* spp and *Daphnia* spp had the largest positive coefficients while *B. longirostris* had the largest negative coefficients. In PC2 *D. galeata mendotae* and *Daphnia* spp had the highest positive coefficients and *Eubosmina* spp and *B. longirostris* had the highest negative coefficients. PC3 had highest positive coefficients for *Acroperus harpae* and *Alonella nana*, and largest negative coefficients for *Eubosmina* spp and

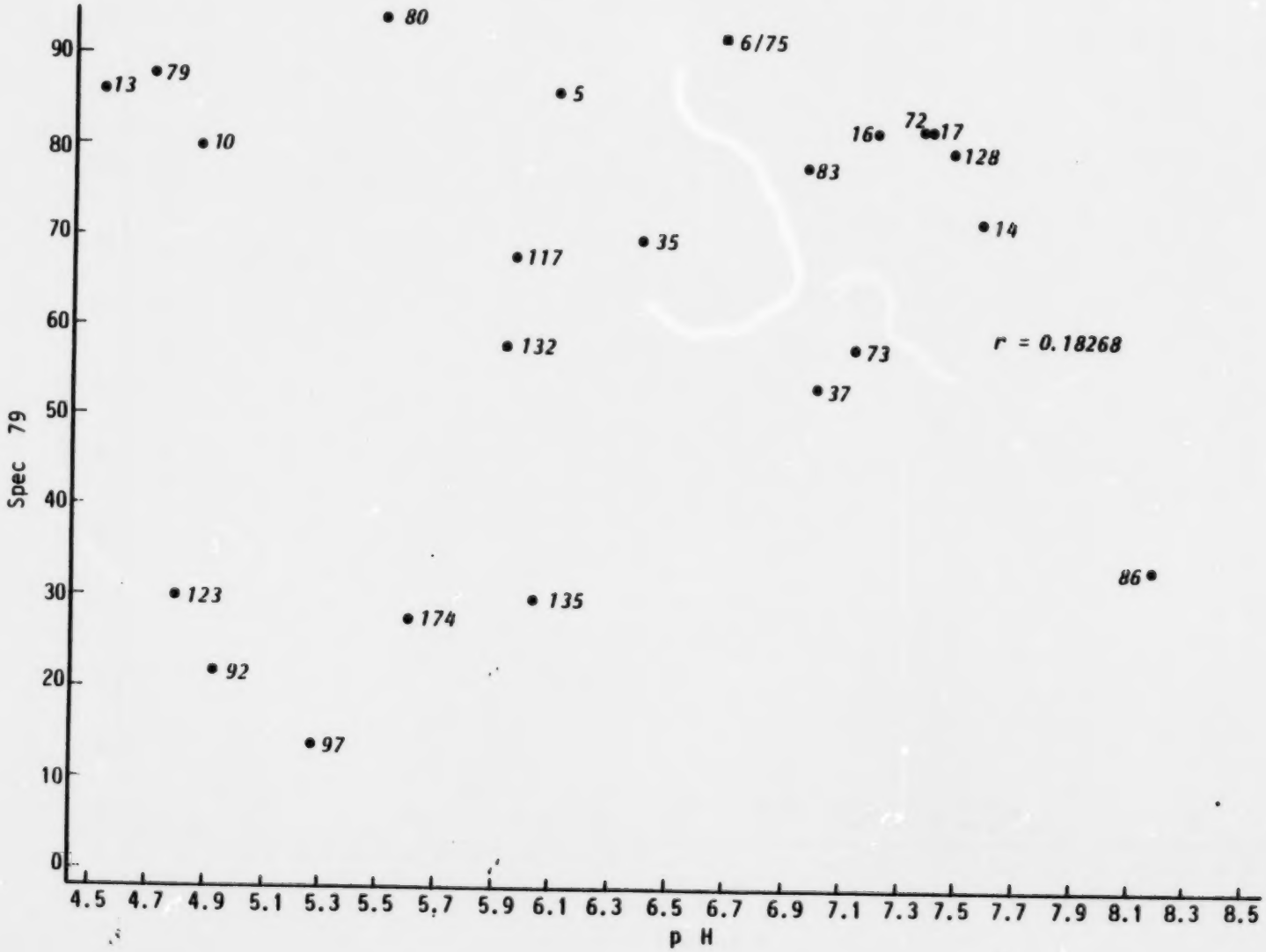

FIGURE 3

PLOT OF RELATIVE ABUNDANCE OF BOSMINA LONGIROSTRIS vs pH

159973 RD

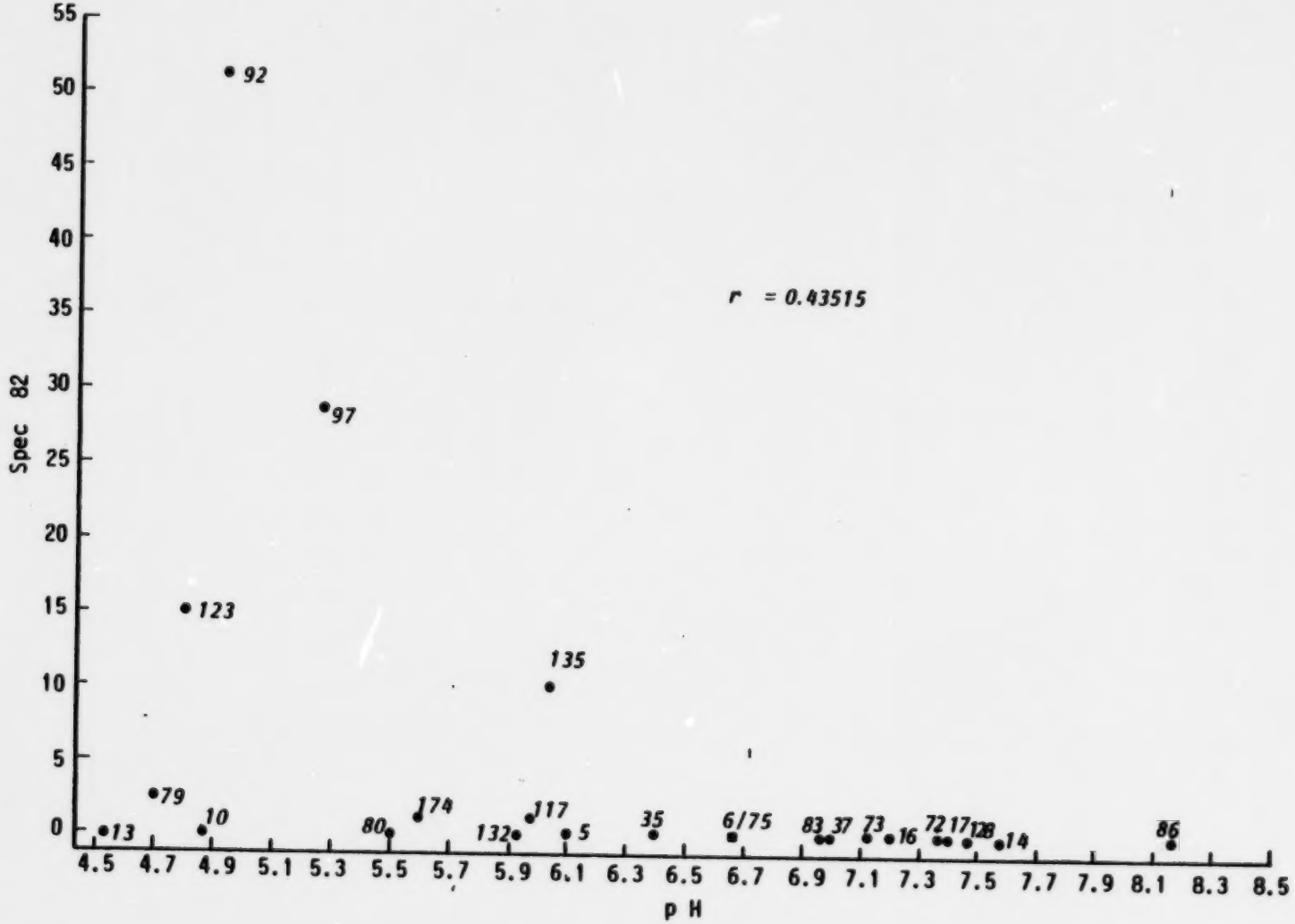

FIGURE 4

PLOT OF RELATIVE ABUNDANCE OF EUBOSMINA spp VS pH

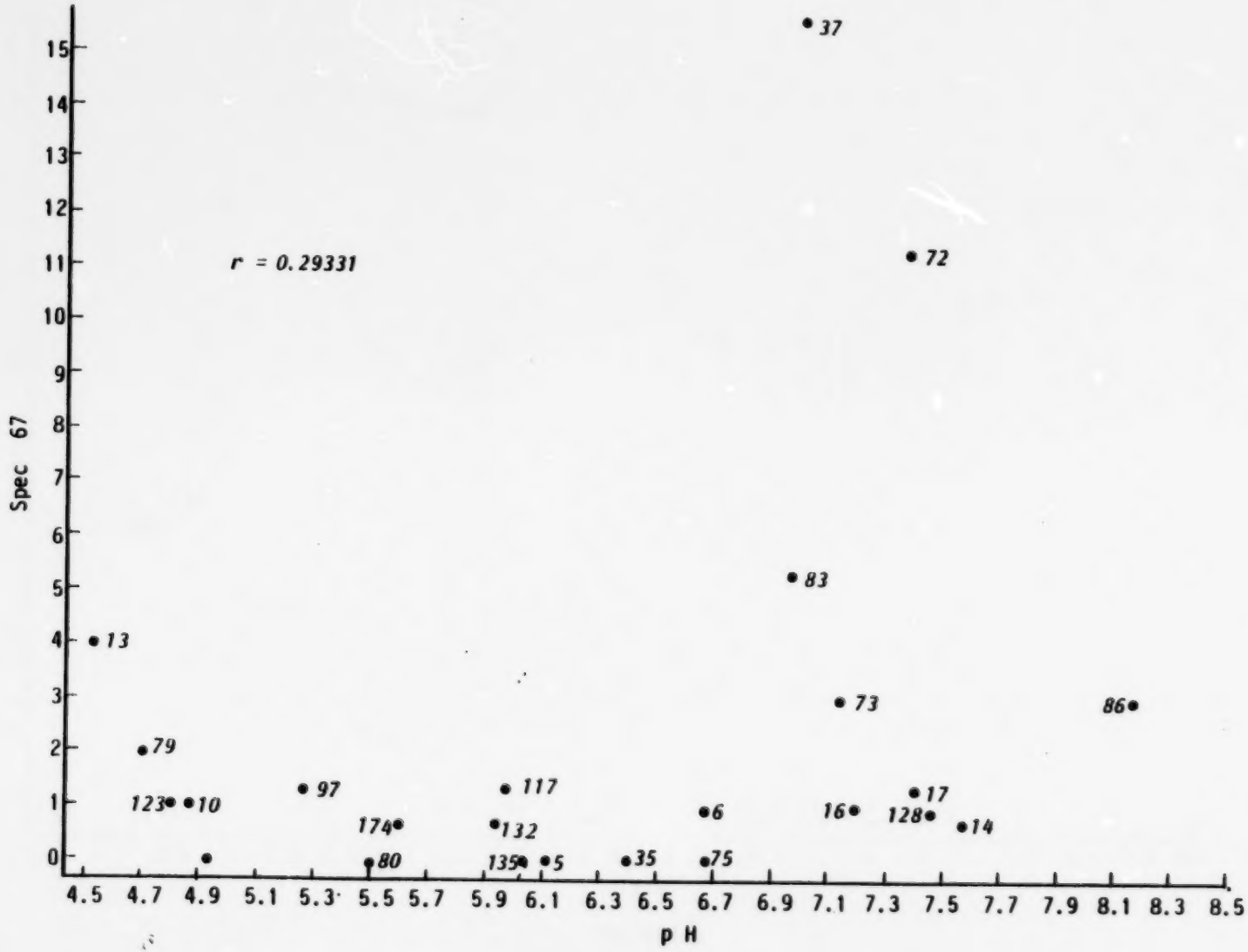

FIGURE 5

PLOT OF RELATIVE ABUNDANCE OF CHYDORUS SPHAERICUS VS pH

158975 RD

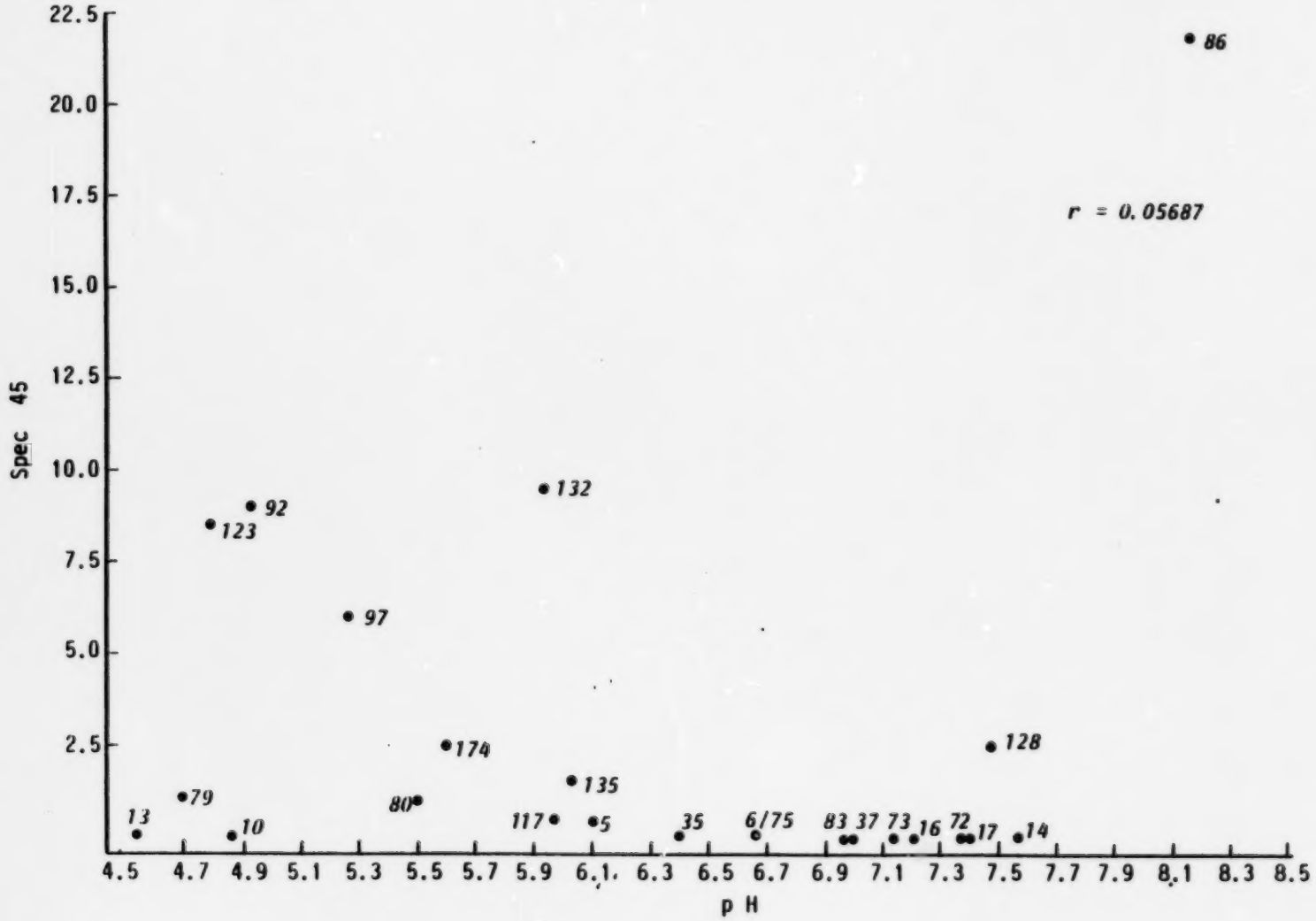

FIGURE 6

PLOT OF RELATIVE ABUNDANCE OF A .ONELLA NANA VS pH

158976 RD

TABLE 4

LAKE GROUPS IDENTIFIED BY MUTUAL INFORMATION ANALYSIS

1	2	3	4	5	6
Clearwater 13	Michaud 174	Fraleck 117	Frederick 123	Leonard 135	Shoofly 86
Wavy 10		Lower Sturgeon 35	Jim Edwards 97		
O.S.A. 79		McKee 128	Sunnywater 92		
George 80		McFarlane 17			
Hele 75		Millerd 14			
Skill 6		Loon 73			
Frenchman 5		Hutton 132			
Raft 16		Kakakiwaganda 37			
Margaret 11					
Elizabeth 72					

MEAN RELATIVE ABUNDANCE (%) OF TEN MOST ABUNDANT TAXA IN LAKE GROUPS IDENTIFIED BY MUTUTAL INFORMATION ANALYSIS

	1	2	3	4	5	6
Bosmina longirostris	85.2	26.4	66.7	21.6	30.6	32.4
Daphnia galeata mendotae	1.4	27.6	10.1	7.1	5.1	0.0
Daphnia spp	0.8	24.7	7.1	9.4	6.4	0.0
Eubosmina spp	0.3	1.2	0.1	30.9	10.2	0.0
Alonella nana	0.3	2.3	1.5	7.6	1.3	21.0
Chydorus sphaericus	2.5	0.6	3.0	0.7	0.0	2.9
Daphnia pulex	0.8	0.6	0.3	2.0	17.8	0.0
Sididae	1.3	0.6	1.9	1.1	2.6	0.0
Acroperus harpae	0.2	2.3	0.5	1.6	0.6	19.1
Alona spp	0.8	2.9	1.0	2.1	0.6	3.8

D. galeata mendotae. PC1, PC2, and PC3 accounted for 76% of the total variation. The taxa which were highly correlated with the three components were the same taxa responsible for the groupings of lakes by the two classification techniques.

When PC1 was plotted against PC2 (Figure 7) the same six lakes (Michaud, Frederick, Jim Edwards, Sunnywater, Leonard, and Shoofly) separated by the clustering techniques were separated along the PC1 axis indicating that the separation is due to real differences in species composition. When PC1 was plotted against individual chemical and physical variables no relationship was found. A plot of PC1 versus pH is shown in figure 8.

Reciprocal averaging separated out the same six lakes as PCA plus Hutton Lake (Figure 9).

The six lakes identified by all four techniques ranged in pH from 4.8 to 8.2 with a large degree of overlap in pH with the remaining lakes.

The use of relative abundances in the analysis described above emphasizes taxa with high relative abundances and gives weight to dominant taxa. Since effects of pH may be identified in the presence or absence of rare taxa reciprocal averaging was repeated on the basis of presence or absence of taxa, an approach which is more sensitive to rare species. The lakes that separated out included Hele, Millerd, Leonard, Margaret, Shoofly and George Lakes, while the remaining lakes were clustered closely. The clustering of the lakes was not related to pH which ranged from 5.5 to 8.2 and overlaped with the pH of lakes in the main cluster. Rare taxa (present in 3 lakes or less) found in the six lakes include: *Ophryoxus gracilis* in Millerd Lake, *Leydigia* in Hele Lake, *Eubosmina tubicen* and *Holopedium gibberum* in Leonard Lake, *H. gibberum*, *Graptoleberis testudinaria* and *Chydorus faviformis* in Margaret Lake, and *Alona circumfimbriata*, *Disparalona rostrata* and *Pleuroxis denticulatis* in Shoofly. However these taxa were not restricted to the lakes in question.

Discriminant analysis was used to determine whether lakes differed chemically or physically in addition to differing in cladoceran species composition. The Lake groups used were those formed by MIA on the basis of species composition. The analysis was performed on groups 1,3 and 4 only, leaving out groups containing single lakes. This analysis separated out group 4 containing lakes Frederick, Jim Edwards, and Sunnywater. Barium, followed by total phosphorus were identified as the two discriminating variables. Barium levels were highest in those lakes included in group 4 (table 5). The analysis was repeated again including only groups 1 and 3. The main discriminating variables identified were total phosphorus followed by iron. The majority of lakes included in group 3 had higher levels of total phosphorus while the majority of lakes included in group 1 had higher levels of iron although there was considerable overlap in the levels of total phosphorus and iron in lakes included in groups 1 and 3 (Table 6).

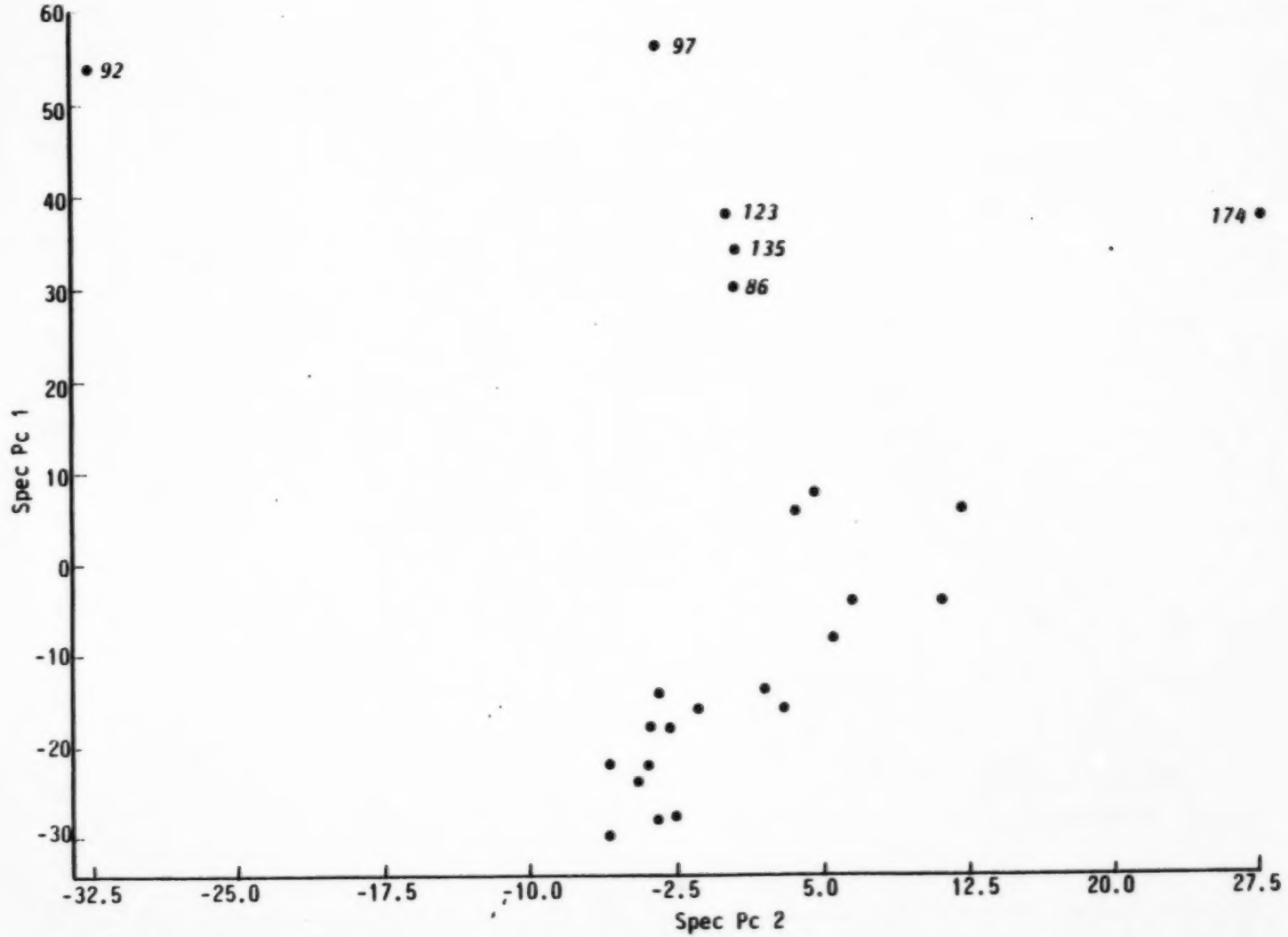

FIGURE 7

PRINCIPAL COMPONENTS ANALYSES PLOT OF SPECPC1 & SPECPC 2

158977 RD

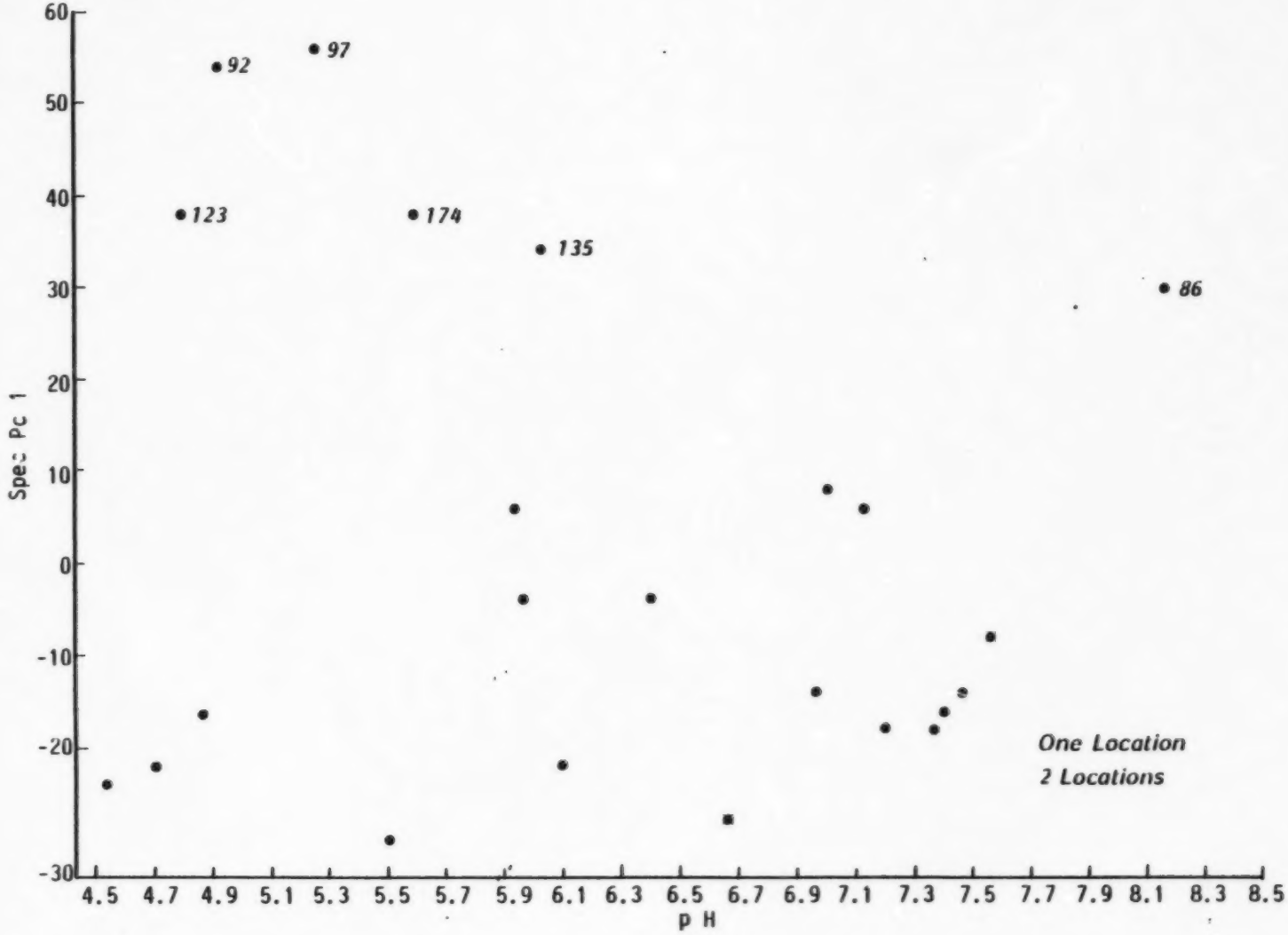

FIGURE 8

PRINCIPAL COMPONENTS ANALYSES PLOT OF SPEC PC1*pH

158978 RD

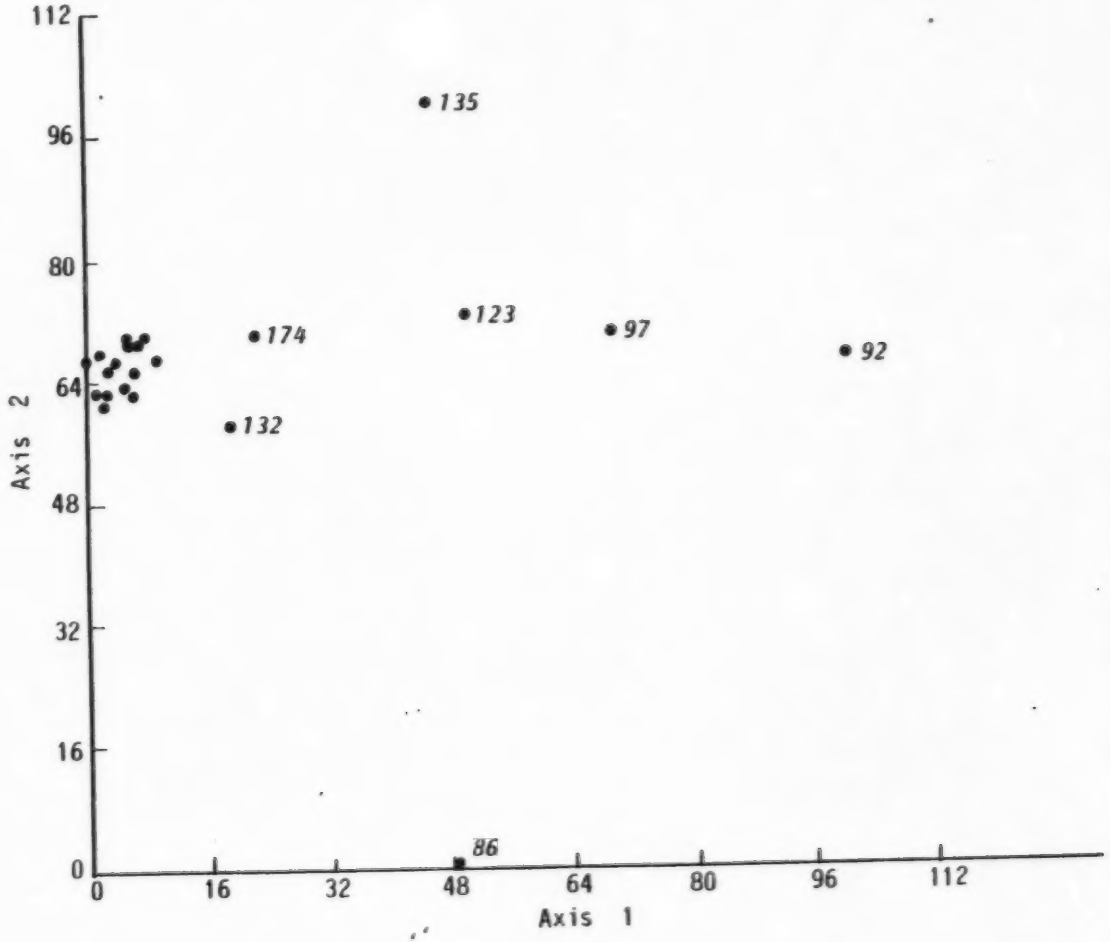

FIGURE 9

RECIPROCAL AVERAGING (SPECIES COMPOSITION)

TABLE 5

DISCRIMINANT FUNCTIONS AND CLASSIFICATION MATRICES

Discriminant Analysis including MIA Groups 1, 3 and 4

Classification function

	Group	1	3	4
Variable	Ba	0.05404	0.07376	0.19085
	Tot P	1.02812	1.72385	1.11191
	Constant	-4.77448	-10.77640	-16.97353

Discriminant Analysis including MIA Groups 1 and 3

Classification function

	Group	1	3
Variable	Fe	0.00912	-0.00961
	Tot P	0.62776	1.51069
	Constant	-3.25096	-7.73477

TABLE 6

ALKALINITIES, DISTANCE FROM SUDBURY (km) AND LEVELS (µg/L) OF BARIUM, TOTAL PHOSPHORUS AND IRON IN LAKES GROUPED ACCORDING TO MUTUAL INFORMATION ANALYSES

	Lakes	Alk	Dist from Sudbury (km)	Barium	Total Phosphorous	Iron
1	Clearwater (13)	0	24	59	4	255
	Wavy (10)	0	21	40	5	275
	O.S.A. (79)	0	56	37	2	125
	George (80)	0	56	61	5	150
	Hele (75)	19	56	22	3	85
	Skill (6)	73	27	9	13	470
	Frenchman (5)	65	29	16	5	145
	Raft (16)	25	10	19	5	70
	Margaret (83)	47	40	8	7	55
	Elizabeth (72)	156	48	5	8	55
2	Michaud (174)	5	42	50	5	155
3	Fraleck (117)	10	48	51	10	35
	Lower Sturgeon (34)	53	48	10	12	110
	McKee (128)	6	101	42	9	100
	McFarlane (17)	202	10	19	12	65
	Millerd (14)	245	24	70	12	65
	Loon (73)	99	56	9	9	130
	Hutton (132)	28	37	41	6	85
	Kakakiwaganda (37)	80	40	11	9	105
4	Frederick (123)	0	85	71	4	180
	Jim Edwards (97)	0	105	184	3	65
	Sunnywater (92)	0	101	180	4	50
5	Leonard (135)	2	198	31	6	815
6	Shoofly (86)	766	97	33	7	95

Of the three lakes excluded from the discriminant analysis Leonard Lake was considerably further from Sudbury than the remaining lakes, Shoofly was the most alkaline of the lakes while Michaud did not appear to be unique in any of the physical or chemical parameters monitored.

On the basis of the discriminating variables identified by the discriminant analysis the separation of lakes by clustering techniques based on species composition is not related to pH. Phosphorus identified as a main discriminant variable is an essential nutrient for phytoplankton growth and is often the limiting factor for primary production in large lakes (Russell-Hunter, 1970). Since phytoplankton are a main food source of most cladocerans the phosphorus levels of a lake can be indicative of the food available to them. Thus in this study, the trophic status of the lake, as indicated by the phosphorus levels, appears to have been the overriding variable in determining cladoceran species composition, possibly masking any effect of pH.

Since no relationship could be identified between the cladocerans and lake pH it was not possible to develop a cladoceran-pH inference system, and the analysis of cladoceran remains in sediment cores as a means of documenting pH history of an acid lake is not recommended.

Although acidic lakes have been reported to contain lower numbers of zooplankton species relative to non-acidic lakes, it is not known whether this is related to direct physiological effects of the acids or increased levels of heavy metals, a change in the available food supply, or changes in the predator-prey relations. Erikson et al (1980) suggest that upon the disappearance of fish from acidic lakes there is the possibility for rapid expansion of invertebrate predators and that such a change in the predator-prey system may be responsible for many of the ecological differences reported for acidic lakes. If this were the case differences in the cladoceran assemblages as related to lake pH would not necessarily be obvious since predator-prey relations can vary substantially between lakes independent of pH.

SUMMARY AND CONCLUSIONS

1. Reduced number of zooplankton species in lower pH lakes found by several investigators was not found for the cladoceran remains in the surficial sediments of 24 shield lakes studied.

2. The distribution of the cladoceran taxa remains in relation to pH was not consistent with that described in the literature.

3. No correlations were found between the relative abundances of individual taxa and individual chemical and physical parameters of the lakes.

4. Mutual information analysis, cluster analysis and principal component analysis performed on the basis of the relative abundances of the cladocerans separated out Lakes Michaud, Frederick, Jim Edwards, Sunnywater, Leonard and Shoofly from the remaining lakes. Reciprocal averaging separated out the same six lakes plus Hutton Lake.

5. Discriminant analysis used to determine whether these lakes differed chemically or physically in addition to differing in cladoceran species composition indicated that the separation of the six lakes was not related to pH.

6. Phosphorus, an indicator of the trophic level of the lakes and the food available to the cladocerans was identified as a main discriminant variable and may have masked any effect of pH on the cladoceran species composition of the lakes.

7. Since no relationship was identified between the cladoceran remains in the surficial sediment and pH of the 24 study lakes a cladoceran-pH inference system could not be developed. Therefore analysis of cladoceran remains in sediment cores to document pH history of an acid lake was not recommended.

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POOR

QUALITY

ORIGINAL